KIEDAISCH

A review of the Keokuk and Hamilton water power project

Civil Engineering

B. S.

1910

A REVIEW OF THE KEOKUK AND HAMILTON WATER POWER PROJECT

BY

KARL KIEDAISCH

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED JUNE, 1910

13F11 Craig.

UNIVERSITY OF ILLINOIS

COLLEGE OF ENGINEERING.

June 1, 1910

This is to certify that the thesis prepared in the Department of Municipal and Sanitary Engineering by KARL KIEDAISCH entitled A Review of the Keokuk and Hamilton Water Power Project is approved by me as fulfilling this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

A N Talbot

Melvin L. Enger

Instructors in Charge.

Approved:

A N Talbot

Professor of Municipal and Sanitary Engineering.

Approved:

Ira O. Baker.

Professor of Civil Engineering.

A REVIEW OF THE KEOKUK AND HAMILTON WATER POWER PROJECT.

HISTORY

Work on the improvement of the Mississippi River between Keokuk, Iowa and Montrose, Iowa, began as early as 1837, when the government undertook the project of excavating a channel in the solid rock.

This undertaking proved to be such a large and expensive project that it was abandoned after 25,000 cubic yards of stone had been excavated at a cost of $335,000.

In 1867, a corps of United State Engineers met at Keokuk to consider the matter of improving the Des Moines Rapids. After a careful consideration they advised the building of a canal along the Iowa shore, between Keokuk and Nashville, a distance of approximately seven and one half miles. From Nashville to Montrose the channel was to be excavated as originally planned. The canal and locks were completed and open to navigation in 1877.

Just preceding the building of the canal the first water power talk started to circulate among the enterprising citizens of the community. Some of the engineers who were investigating the project as regards navigation suggested that it would be just as cheap to build a dam across the foot of the rapids as it would be to build the canal, and by this means not only aid navigation but develop water power at the same time. The Government engineers decided that it was their object to aid navigation and not to develop water power.

In 1900 a Keokuk, Iowa and Hamilton, Illinois, Water Power Company was organized and incorporated under the state laws of Illinois. This company had among its members some of the most prominent men of both of the cities. The company managed to raise enough money from its members to bring a civil engineer, Lyman E. Cooley, down from Chicago to investigate the project as to its feasibility as an engineering and financial undertaking. Mr. Cooley reported that in order to develop power a dam would have to be built at the lower end of the rapids opposite Keokuk. As the government franchise restricted the company from damming the river they endeavored to interest the government in building the dam.

After a great deal of urging on the part of the company a Board of United States Engineers convened at Keokuk in 1903. It was decided at this meeting that the dam would aid navigation, in that it would do away with two of the locks and would keep the stage of the river practically constant, but that the saving would not warrant the government's investing the necessary sum to carry out the idea. The decision of the engineers aided the company in having its franchise changed so that it read that any company could build the dam upon the approval of the plans by the Secretary of War. On account of the lack of funds the project was dropped. Only a few of the most enthusiastic members of the company believed that they would ever be able to raise the necessary amount of cash.

In January of 1905 the City Council of Keokuk appropriated $2,000 to send a committee of men to Washington, D. C. After nearly a month of lobbying, this committee finally got the attention of the Interstate Commerce Committee. Mr. Cooley was

sent for and made a report to the Committee. The Committee reported favorably and then it was but a matter of time for the option, as it now stands, to receive the signature of the President.

Mr. Hugh L. Cooper, of New York City, who now controls the water power project was given the option on September the 15th 1905. In the following summer a corps of some forty engineers, rodmen etc., made the surveys on both sides of the river from Keokuk to Burlington, Iowa. The investigation was then carried on by Mr. Cooper in his New York office until 1908, when he bought the franchise for $20,000.

On January 8th 1910, Mr. Cooper began construction on the dam which will be the largest water power dam in the world.

DRAINAGE AREA

As this dam is to dam the Mississippi River, little need be said in this report in regard to drainage area. It is a well known fact that the upper Mississippi drains enough area to insure its never going dry. The estimated flood flow at Keokuk is 372,500 cubic feet per second and the minimum flow is 20,000 cubic feet per second.

LOCALITY

Keokuk, Iowa and Hamilton, Illinois and the site of the proposed dam, are located at the foot of the Des Moines Rapids, of the Mississippi River, which extends from Montrose to the north to nearly the mouth of the Des Moines River. This is approximately fifteen miles. The gorge of the river at these points is approximately one and one-fourth miles wide, at the site of the dam it is 6,000 feet. The bluffs on the west, or Keokuk side, are precipitous and somewhat so on the east side. They vary in

height from 150 feet to 256 feet. After the upland is reached it is found to be comparatively level. The elevation varies from 650 to 750 feet above mean sea level. The precipitous bluffs and the narrow gorge for so many miles up stream make this locality almost ideal for the building of this great dam.

Figure (1)-Appendix E is a plan drawing of the Mississippi River at Keokuk and shows the location of the spillway, power plant, government lock and dry dock.

PLANT

The power plant is to be of steel, brick and concrete construction. The general dimensions will be 1408 feet long, 123 feet wide, and 133 feet high, above the base of the dam. The building will be well lighted as nearly the entire side area is taken up by the large windows, three-fourths of the length being window area. A transformer bay runs through the center of the building for its entire length with a wiring conduit just above this bay. Two large traveling cranes, which will be used in hoisting the generator parts and the screens for the turbine passages, run the entire length of the building on a track built in the side wall. The ice chutes, Figure (4) Appendix E, through which all the ice that accumulates between the submerged arches and the water passage screens will be shot, are located at the middle and upper end of the plant. The two sets of exciters are located at the ends of the main section of the plant. Besides these the equipment of the plant will consist of 30 main units of 10,000 Electrical Horse Power each, and transformers and switch boards. Figure (2) Appendix E shows the arrangement of the generators in the plant while Figure (3) Appendix E is a section through the plant.

DAM

The dam, including abutments, will be 4,700 feet in length. The section which comprises the spillway only, will be 4,400 feet in length. Its height will be 37 feet above the river bed, and its base 43 feet wide. The upstream face will be perpendicular, while the down stream side will be an ogee curve, the upper portion a parabola, over which the water will spill, the lower portion an arc of a circle which will throw the water horizontally away from the toe of the dam.

On top of the spillway will be placed 116 steel flood gates, 30 feet wide by 11 feet high, supported by concrete piers. These piers will be 8 feet thick and 29 feet wide. They will be built integral with the dam, being carried down to bed rock on the up stream side. These piers will also support an arched bridge, from which the gates will be opened by electrical hoists. By manipulation of these gates the water above the dam will be kept at a constant level at all seasons. See Appendix A. These electrical hoists will also be used in picking up stray logs and refuse and dropping it below the dam.

The dam will be built as a gravity section, its weight and size being enough to prevent overturning, sliding and crushing. See Appendix B. No reinforcing will be used in its construction. It will practically be a monolith of concrete imbedded in the solid rock of the river bed.

ICE-FENDER

To prevent floating ice and logs from entering the power house, an ice fender will be built upstream, from the upper end of the power house, and coming to a junction with the shore.

To the eye this fender will appear as a solid wall of concrete, 2,800 feet long, fencing off the power house from the river. In reality the fender will be composed of large sunken arches 100 feet long and 35 feet high. The piers between the arches will be 12 feet wide and varying in thickness from 6 feet at the top to 16 feet at the base. Details of the construction of the fender are shown in Figure (4) Appendix E.

LOCK AND DRY DOCK.

The construction of the dam will entirely drown out and destroy the present Des Moines Rapids Canal with its three locks and dry dock. In place of these will be built one large lock and a dry dock. This lock will be a great deal wider and larger than the present lock, in fact it will be large enough to allow any boat to go through that will be built for navigation on the river for a great many years in the future.

The number of lockages will be reduced from three to one, and in place of the shallow canal a deep lake one mile wide and 30 miles long will be formed above the dam. This lock when complete will be furnished with the latest locking machinery. The dry dock located just at the side of the lock, will be operated, as will the lock, by the Government. Figure (6) Appendix E is a plan and arrangement of the lock and dry dock.

FLOW, POWER, HEAD

The minimum flow of the river available for water power may very conservatively be taken as 20,000 cubic feet per second, while the maximum at flood time as 372,500 cubic feet per second. The minimum flow, with the fall as the construction of the dam calls for, can be depended upon to deliver at least 60,000 elec-

trical horse power as far as St. Louis, during the time of severest draught, or when the flow is choked up by ice, for twenty-four hours per day and seven days a week. Under a load factor of 60%, in other words for an average of 14.4 hours per day out of each twenty-four. This would serve for the delivery of 100,000 electrical horse power without recourse to steam. In addition to this a flow of water more than sufficient to yield an additional 100,000 electrical horse power under a 60% load factor. The plant as designed will give the full 100,000 horse power proposed for first installation, or 200,000 horse power of the final installation, in time of flood, under the reduced fall without recourse to steam. See investigation of turbines Appendix C. The available head at time of low water is assumed as 34 feet, and at time of flood as 20 feet. This decrease in head is due to the narrowness of the river bed below the dam, causing the river to back up against the dam. See Appendix A.

SURVEY AND GEOLOGY.

In the summer of 1906 a survey of the flood area was made. The survey was carried on by two parties, one on each side of the river. Each party was composed of transit men, level men, rodmen, chainmen and recorders. The level party was kept just in advance of the transit party. On the Iowa side of the river four separate lines were run in at one transit setting. The lines were the high water line, in time of flood after the dam is built, the highest flood line, under the present conditions, the C. B. & Q. Railroad line, (old location) and the present water line. All section lines and property lines were located as the transit party came along. In other words a sort of a topographical survey was

made of the flood area. All work was checked as to azimuth and elevation on the U. S. Geological Surveys permanent triangulation stations along the way. At intervals of about a mile private permanent stations were placed in the ground, usually near or on a fence line. These permanent stations consisted of a piece of cast iron pipe about four feet in length and two inches in diameter. A cap was screwed on the end of the pipe and a small hole bored in this cap for the rod point. These stations were referenced in by large trees, houses, barns and other permanent properties. This survey extended from Keokuk to Burlington. A similar survey was carried on by the party on the Illinois side of the river. The flood area as determined by the survey comprised some 12,800 acres of land, part of this being very valuable, especially on the Iowa side. The flood area took in several valuable property blocks in the cities of Montrose and Fort Madison. In Fort Madison the entire Santa Fe Railroad shops were included within the flood area. The original plans were changed, by lowering the height of the dam, in order that this part of the flood area was omitted. Thus a great expense was avoided.

In connection with the survey a geological report of the vicinity of the dam was compiled. The foundation was found to be ideal. The limestone which forms the bed of the river is comparatively level and free from spots of rotten rock, gorges and caves. The strata forming the beds of the vicinity of the Mississippi are principally limestone and shales of the Lower Carboniferous Mississippian Series. For range of formations see Appendix D.

By a study of the geological map it is evident that Keokuk is the lowest point in a broad syncline, the limits of

which are Burlington to the north, and Hannibal to the south. From Montrose to Keokuk, the Mississippi flows down on the surface of this hard and resistant chert formation. Near the north boundary of Keokuk the river crosses the axis of the syncline and the strata begin to rise, thus forcing the river to cut its way through the chert, otherwise a natural dam would be formed at this point. It is thus seen that the geological structure is extremely favorable to the development of rapids and to their culmination and abrupt ending at Keokuk. The bed rock crosses the entire breadth of the stream. The length of the rapids is 11.1 miles and the vertical fall is 22.17 feet, or nearly two feet to the mile. The rate of descend is more at the lower end, there being a fall of four and one-half feet in the last mile and nearly eight feet in the last two miles.

The bed rock at the site of the dam is ideal. Drill and rod soundings show from bluff to bluff a remarkable uniformity of depth. For the eastern half of the gorge the bed rock is more or less deeply covered by bars of sand and gravel, forming a flood area with its bayous or sloughs separating Hamilton from the main channel of the river. The bed rock is just as deep and as uniform here as it is on the western side of the gorge where the river flows over the bare rock. The rock forming the bed plain is very tough chert and insoluble limestone and sandstone. The main thing is that this stone is solid and not honeycombed or rotten. The solution of the limestone, if it does dissolve, will be practically zero when the dam is built, and a deposit of silt in the basin has sealed it up. The small amount of fine silt that will settle will only aid in making the dam and its bedrock floor more absolutely

water tight.. The silt will form but slowly because the back water of the dam will extend from 40 to 50 miles and the bars, islands and banks included in this reach will, on account of the slackened current, suffer little erosion remaining almost intact. The deposition of sand and coarse silt must begin at the upper end and therefore it will be a very long time before it will encroach on or reduce the reservoir capacity of the basin.

STRUCTURAL MATERIALS

Since the dam is to be constructed of concrete and cyclopean masonry no local source of cut stone need be sought. The main questions seem to be; first, as to the suitability of local stones for concrete aggregate in work of this character; second, as to beds capable of furnishing suitable blocks of cyclopean masonry; third, as to quarry sites where aggregate could be most conveniently and advantageously obtained.

The stones for aggregate may be taken from the river bed during the excavation for the dam foundation. This chert which forms the surface of the river bed would make a good aggregate, but as limestone is mixed with this, it would seem advisable to separate them. The chert would form a very good aggregate as it is angular in its fracture. Its chemical nature which is like that of quartz sand is favorable to the slow development of a more perfect union of aggregate and cement. This tendency is less to be expected in the limestone aggregate. The best method of making use of both the chert and the limestone would be to separate the two, and then use the chert as an aggregate for the surface of the dam and the limestone for the body. This would make the dam proof against any weakening by the solution of the aggregate as the

limestone would not be exposed to the chemical action of the water. In all probability enough chert could be taken from the river bed in excavating to be used for this purpose. Quarry sites on the west side may be located at any convenient place, as the bluff is a solid wall of stone.

Sand which is of a desirable quality forms extensive bars in the river and may be had by merely dredging, or by more direct means, during low water. Probably enough sand would be obtained in excavating for the dam to be used in making the concrete.

Portland cement is manufactured just 50 miles below the dam site on the river, thus making it easy of access and cheap freight rates could be obtained, as it could be shipped either by boat or rail.

TURBINES AND AUXILIARY POWER

The main units to be used in this plant are to be vertical reaction turbines connected in tandem, two wheels on each shaft. The units are designed especially for the conditions at this plant. The tandem method is used because of the necessity of reducing the diameter of the wheels in order to get the required speed and power.

This arrangement saves space, but the extra cost of foundation more than makes up for this saving. The arrangement of the bearings, is also a very important matter to consider. A really satisfactory bearing for vertical turbines in tandem has not as yet been found. It remains to be seen if the bearings to be used will prove satisfactory. The governors used in regulating the speed of the turbines operate by throttling the water at the intake. There are two sets of exciters used in connection with the

generators. For design of turbine see Appendix C.

Both at the entrance to the penstock and the exit there are gates that may be closed when the turbine is in need of repair or when not in use.

No auxiliary power will be used in connection with this plant, as a sufficient number of units will be installed, so that if any or several are ever out of commission, or at time of high water, there will still be enough remaining to develop the required amount of energy.

Figure (7) Appendix E is an outside elevation of one of the 10,000 horse-power turbines. Figure (3) Appendix E is a section through the plant and shows the location of the turbine and the size of penstock etc.

PROBABLE COSTS

Estimate of Costs.

Flood rights on 12,800 acres at $75.00	$640,000.00
Main Spillway Dam, 169,470 Cu. yds. at $3.00	$509,410.00
Coffer Dam per cu. yd. spillway, at $1.00	$169,470.00
Hydraulic Equipment	$5,940,000.00
Transformer Bay and Equipment	$2,100,000.00
Electric Equipment	$4,200,000.00
Power House	$4,500,000.00
Lock and Dry Dock	$500,000.00
	$18,558,880.00
Engineering contingencies etc. at 10%	$1,855,888.00
	$20,414,768.00
Interest at 4% for 3 yrs.	$2,449,772.00
Total Cost	$22,864,540.00

OPERATION

The operation will probably require thirty men, chiefly mechanics and electricians. The salaries of these men will in

all probability range from $900.00 to $2,000.00 a year.

MAINTENANCE

The maintenance of the entire plant will be very small as the spillway and accessories will require very little repairing. The only parts that will require replacing frequently will be the bearings and parts of the turbines. These repairs will probably constitute the greatest part of the maintenance cost.

MARKET FOR ELECTRICAL POWER

Contracts have been executed with the Public Service Corporation of St. Louis, Missouri, by which they will receive 60,000 Electrical Horse-Power upon the completion of the plant. This contract constitutes the main distribution of power at present, but later the contracts that are under consideration with all of the cities within a radius of 50 miles will be taken up. This power will be regarded as dependable and its low cost will make it very attractive to all customers. A survey is being organized for the route of the conduit line to St. Louis. It is estimated that this line with its steel towers and copper cable will at least cost $1,000,000.00.

SUMMARY

Since the foundations are not deep, the coffer dam work will be of an exceptionally simple and safe character. There is ample warning of floods before they arrive and the river rises but slowly. Rock for concrete and rubble concrete may be had, of excellent quality, from the wheelpit and tail race excavations, and any additional quantity may be had from the river bed, or the banks in close proximity to the site of the works. Sand can be had in unlimited quantities by merely digging it out of the river

bed near at hand. Portland Cement is made by one of the principal manufacturers at Hannibal, about 50 miles down the river, from where it can be brought by boat or rail under conditions favorable for minimum freight rates.

APPENDIX "A".

In order to make certain as to the actual head on the turbines that can be obtained from the maximum and minimum flow, an investigation was made by using Francis Weir Formula. The assumption was first made that the spillway acted as a large weir and the water flowed freely over the dam. With this assumption a curve was plotted for both the head and tail water. By making this assumption it was found that it would be impossible to keep the head water at a constant elevation. To overcome the variation in elevation stop-logs were placed in the 30 foot openings of the spillway. By the manipulation of these stop-logs in the form of gates, the elevation will be kept at a constant elevation of 525 feet up to the time when 142,000 cu. ft. per second is flowing. When the quantity is greater than this the gates will be opened or so regulated as to keep the minimum head at least 20'.

HEAD ON WEIR BY FRANCIS WEIR FORMULA.

$$Q = c(1-.2H)H^{\frac{3}{2}}$$

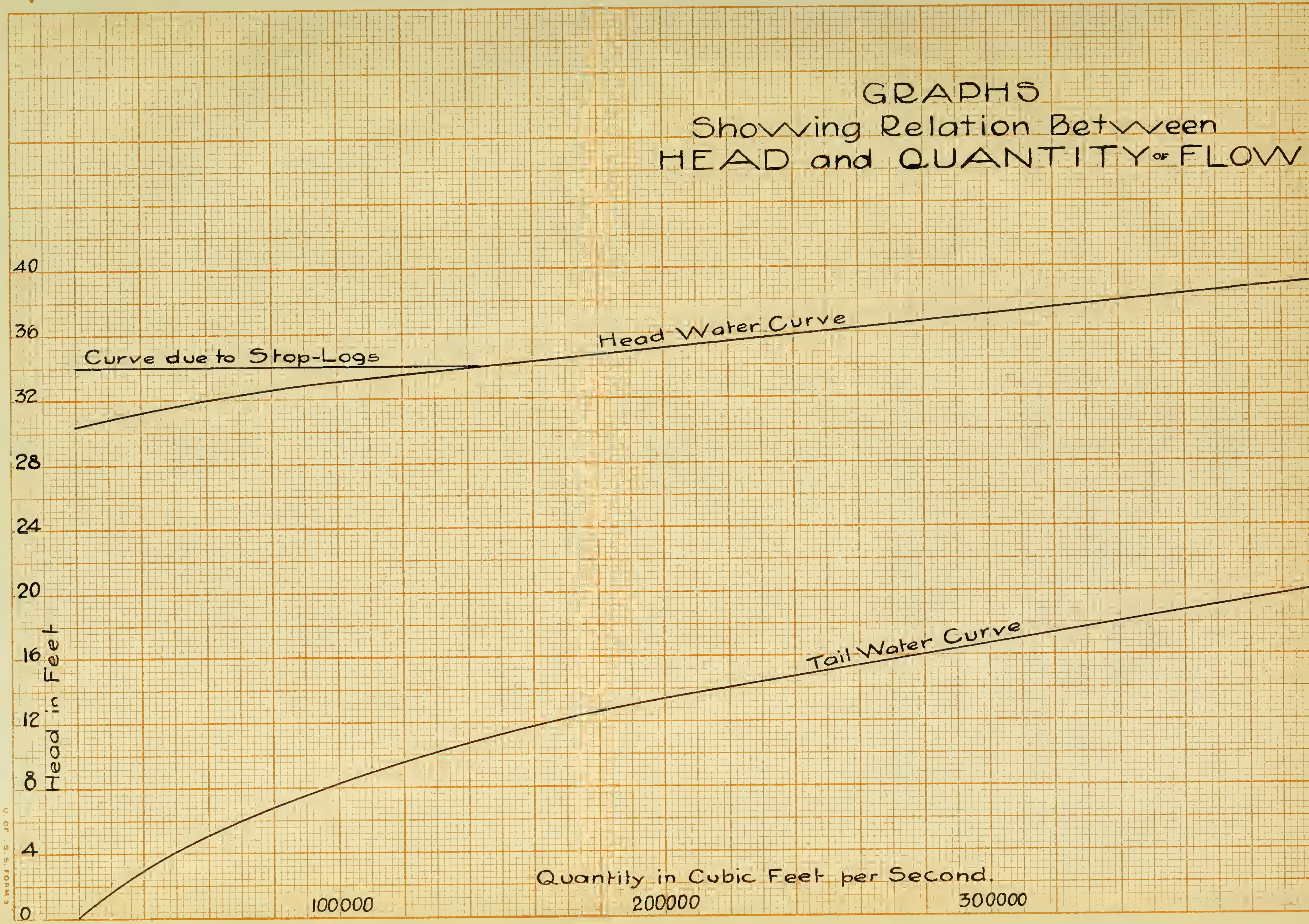
Quantity cu. ft./sec.	$\frac{\text{Quantity}}{116}$	Constant c	Head on weir	Head above L.W.
20,000	172.5	3.5	1.4'	30.4
27,000	233.0	"	1.7'	30.7
30,500	263.0	"	1.9'	30.9
40,300	347.0	"	2.25	31.25
54,000	465.0	"	2.7	31.7
63,000	543.0	"	2.95	31.95
75,000	646.0	"	3.35	32.35
85,000	732.0	"	3.65	32.65
97,000	836.0	"	4.00	33.00
110,000	950.0	"	4.35	33.35
370,000	3190.0	"	10.1	39.10

U. S. GOVERNMENT STREAM FLOW RATING TABLE.

Stage in feet	Quantity cu. ft./sec.
Zero	20,000
1 ft.	27,000
2 ft.	30,500
3 ft.	40,300
4 ft.	54,000
5 ft.	63,000
6 ft.	75,000
7 ft.	85,000
8 ft.	97,000

U. S. GOVERNMENT STREAM FLOW RATING TABLE.

Stage in feet	Quantity cu. ft./sec.
9 ft.	110,000
19 ft.	370,000

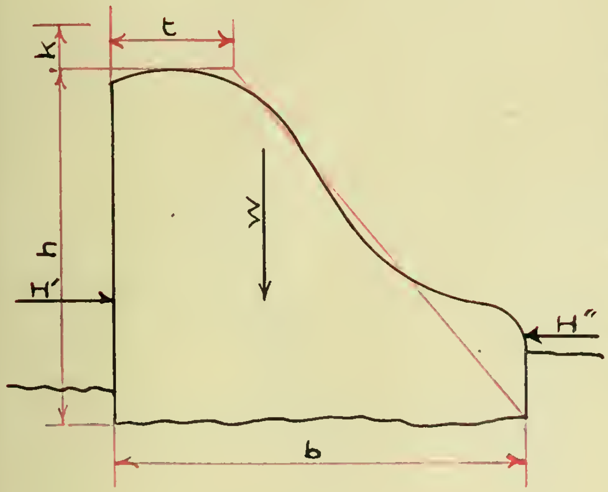

GRAPHS
Showing Relation Between
HEAD and QUANTITY OF FLOW
Head Water Curve
Curve due to Stop-Logs
Tail Water Curve
Head in Feet
Quantity in Cubic Feet per Second.
0
4
8
12
16
20
24
28
32
36
40
100000
200000
300000

APPENDIX "B".

The dam or main spillway was investigated for stability in the following cases, sliding, overturning and crushing at the toe. It was found that a large factor of safety was used in all cases and that no failures should occur due to any of the above causes.

The investigation was carried on as follows, according to the formulas and notation in Baker's Masonry Construction.

SLIDING.



H'= Horizontal pressure of water.

h = Height of dam.

k = Depth of flow over dam.

H"= Horizontal pressure on back of dam due to water.

W - Weight of masonry section.

w = 150 pounds per cubic feet.

t = Thickness at top.

y = Friction factor = .75

$H' = 31.25h^2 + 62.5hk$

$= 31.25 \times 37^2 + 62.5 \times 37 \times 5$

$= 54450$ lbs.

$H" = h \times 1 \times \frac{h}{2} \times 62.5$

$= 8 \times 1 \times 4 \times 62.5$

$= 2,000$ lbs.

Total $H = H' - H" = 54,450 - 2,000 = 52,450$ lbs.

$W = w \left[ht + \frac{h}{2} \times (b-t) \right]$

$= 150 \left[37 \times 13 + 18.5 \times 24 \right]$

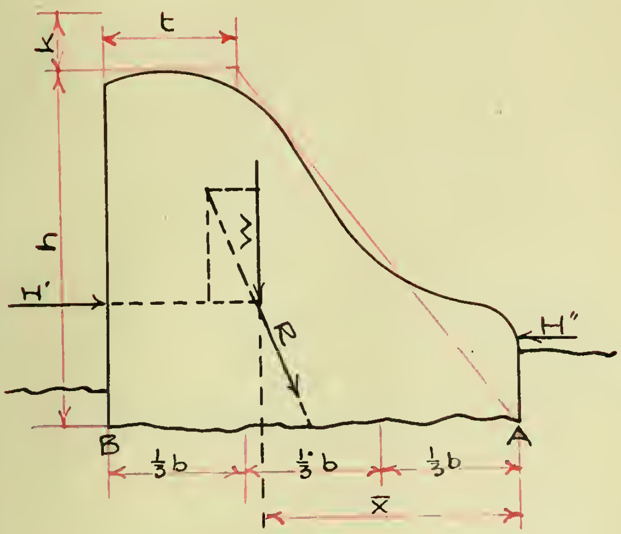
$= 138,750$ lbs.

Condition for Equilibrium $H < yW$

$52,450 < 104,000$

Factor of Safety $= \frac{104,000}{52,450} = 2.-$

OVERTURNING.



Moment due to water at A = $\frac{1hH}{3}$

$$= \frac{1}{3} \times 37 \times 52,450 = 735,000$$

$\bar{x}$ = Distance to center of gravity from A

$$= \frac{2 \times 43}{3} - \frac{13^2}{3(13+43)}$$

$$= 27.7'$$

Moment due to Masonry = W x Ag

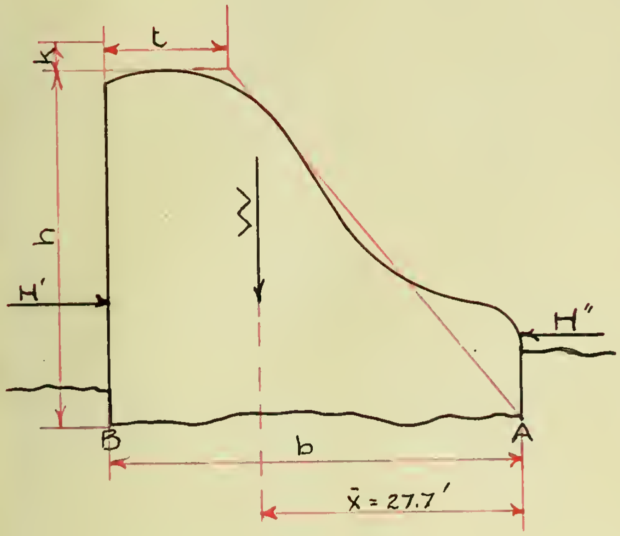
$$= 150(37 \times 13 \quad 18.5 \times 24)\bar{x}$$

$$= 138,750\ \bar{x}$$

$$= 3,850,000 \text{ lb. ft.}$$

The resultant of H and W passes through middle of middle third of base and therefore is stable.

CRUSHING AT TOE.



Water running over dam.

M = Resulting moment due to water.

W = Weight of unit section of dam.

P = Maximum pressure per unit of area.

l = Length of section in units, A to B.

$\overline{x}$ = Distance center of gravity from A in unit.

$$P = \frac{4W}{l} - \frac{6W\overline{x}}{l^2} + \frac{6M}{l^2}$$

$$= \frac{4 \times 138,750}{43} - \frac{6 \times 138,750 \times 27.7}{43^2} + \frac{6 \times 735,000}{43^2}$$

= 19.4 lbs. per square inch

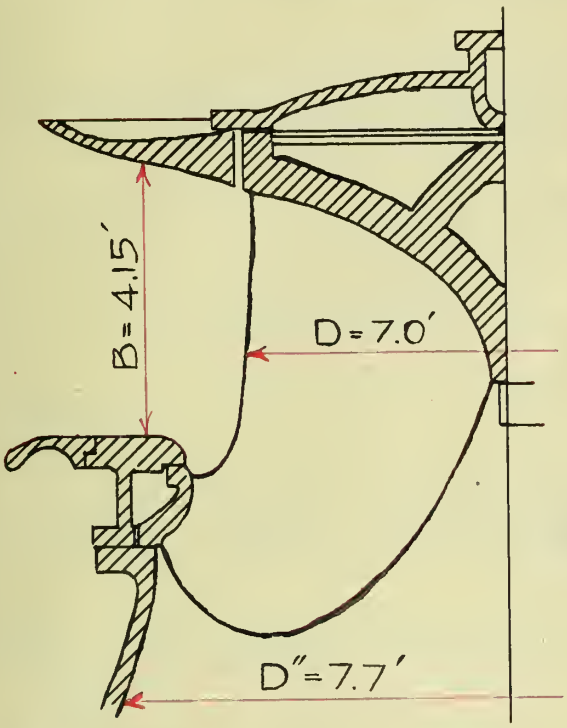
The allowable shearing stress of concrete alone is 30 lbs. per sq. in. As the compressive strength at the maximum point is within this limit the dam will not fail, due to shear at any point.

APPENDIX C.

The turbines to be used are to be of special design. In order to determine whether the tandem wheels are feasible, a rough design was made by the writer according to a method published by Professor S. J. Zowski in the Engineering News of January 6th 1910.

PROFILE OF ALLOWABLE RADIAL INWARD FLOW TURBINE

HIGH-SPEED AND HIGH CAPACITY, LOW HEAD.



H = Head of water.

H-P = Electrical horsepower developed.

N = Number of revolutions per minute.

Eff. = Assumed efficiency.

Q = Quantity water necessary.

D = Diameter of wheel.

β = Bucket angle.

α = Vane angle.

B = Entrance diameter.

D" = Discharge diameter.

Given:-

H = 34'

H-P = 10,000 E.P.H.

N. = 90 r.p.m.

Eff. = 80%

$$Q = \frac{11 \times 10,000}{34} = 3.240 \text{ cu. ft. per sec.}$$

$$Kt = \frac{90 \times \sqrt{10,000}}{34 \times \sqrt[4]{34}} = 106.5$$

As this value of Kt is greater than those given in the table a multiplex system must be used, say two wheels on one shaft, then-

$$\text{Kt becomes } \frac{106.5}{2} = 53.3$$

Now from the table it will be seen that a High-Speed and High-Capacity runner may be used, with bucket angles, varying from 90 degrees to 135 degrees.

Then from equation "5"

$$D = \frac{106.5}{90} \times \sqrt{34} = 6.9' = 83" \qquad \text{Say } 7'$$

Speed constant

$$K_v = \frac{\pi DN}{60\sqrt{H}} = \frac{\pi \times 6.9 \times 90}{60\sqrt{34}} = 5.57$$

Assuming $e_h = .8$ hydraulic eff.

$$\therefore \sqrt{e_h g} = \sqrt{.8 \times 32.5} = 5.1$$

then

$$\frac{K_v}{\sqrt{e_h g}} = \frac{5.57}{5.1} = 1.09 = \sqrt{\frac{\text{Sin. }(\beta - \alpha)}{\text{Sin. }\beta \text{ Sin. }\alpha}}$$

From curve in fig. 2, Could use

$$\beta = 120^\circ \quad \alpha = 19^\circ \quad \text{or} \quad \beta = 110^\circ \quad \alpha = 27^\circ$$

Choose the former as the turbine must be capable of carrying overload.

For these angles value of

$$\sqrt{\frac{\text{sin. }\beta}{\text{sin. }(\beta - \alpha)\cos\alpha}} \times \sin\alpha \quad 0.31 \quad \text{fig. } 6$$

Consequently the radial entrance velocity

$$C_r = .31\sqrt{e_h g H} = .31 \times 5.1 \times 5.83 = 9.2$$

Number of vanes from fig. 4 is 19.

The guide case is designed so that $t' = 0$

$$\text{Free Circumference} = \pi D - \frac{nt}{\sin\beta} = 3.1416 \times 83 - \frac{19 \times \frac{1}{4}}{.707} = 254.3" = 21.2'$$

Hence

$$21.2 \times B \times 9.2 = \frac{3240}{4}$$

$$B = 4.15' = 49.8"$$

Ratio of width to diameter

$$\frac{49.8}{83} = \frac{1}{1.67} \qquad \frac{1}{1.67} > \frac{1}{2} \quad \text{O.K.}$$

Draft tube velocity

$$c'' = \sqrt{2g \times .14 \times 34} = \sqrt{306} = 17.5' \text{ ft. per sec.}$$

.14 allow draft tube loss.

Diameter of Draft tube

$$\frac{\pi D''^2}{4} = \frac{3240}{4} \times \frac{144}{17.5} \qquad \frac{3.1416 \times 10.5}{4}$$

$$D''^2 = 8500.25$$

$$D'' = 92.25'' = 7.7'$$

APPENDIX D.

The range of formations as found by well borings all over the United States, is as follows:-

Age	Formation No.	Description	Thick. ft.	Depth ft.	Elev. ft.
Upper Carboniferous	Coal Meas. 19	Sandstone, shale, clay and coal	36	36	637 to 601
	18	Brecciated Limestone	14	50	587
	St. Louis 17	Blue Sandstone	8	58	578
	16	Limestone Magnesium	12	70	567
Lower Carboniferous	15	Limestone Shaley (Geode formation)	40	110	527
	Keokuk				
	14	Limestone, Massive	60	170	467
	13	Chert and Limestone	80	250	387
	Burlington 12	Limestone, Massive	40	290	347
	11	Shale, Calcareous	65	355	282
	10	Limestone, Massive	10	365	272
	Kinderhook 9	Limestone, shaley	195	560	77
Devonian	Hamilton 8	Limestone, shaley	65	625	12
	Oriskany 7	Water-bearing sandstone	20	645	8
Silurian	Niagara 6	Limestone sandy,	55	700	63
	5	Water-bearing sandstone	37	737	100
Ordovician	Hudson 4	Shale	63	800	163
	Trenton 3	Limestone	140	940	303
Cambrian	Ozark 2	Sandstone	110	1050	413
	1	Limestone Magnesium	755	1805	1160

APPENDIX E.

On the following pages are presented drawings of the plant and accessories.

PLAN AND LOCATION OF DAM

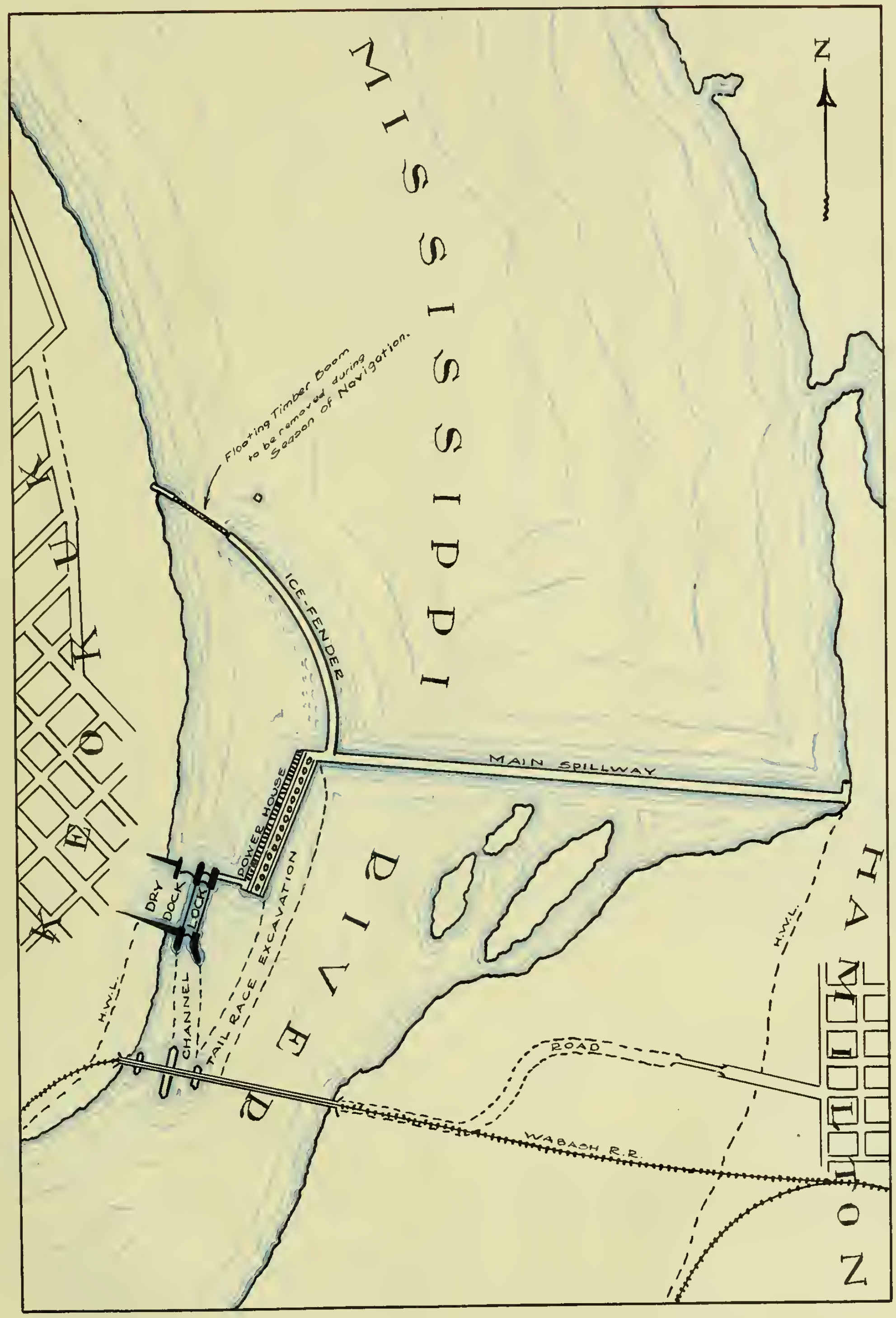
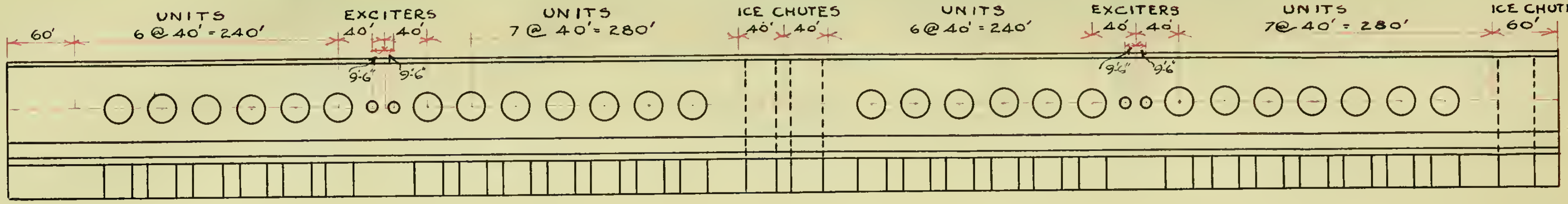


Fig. 1

FLOOR PLAN OF POWER HOUSE



DAM STOP-LOG

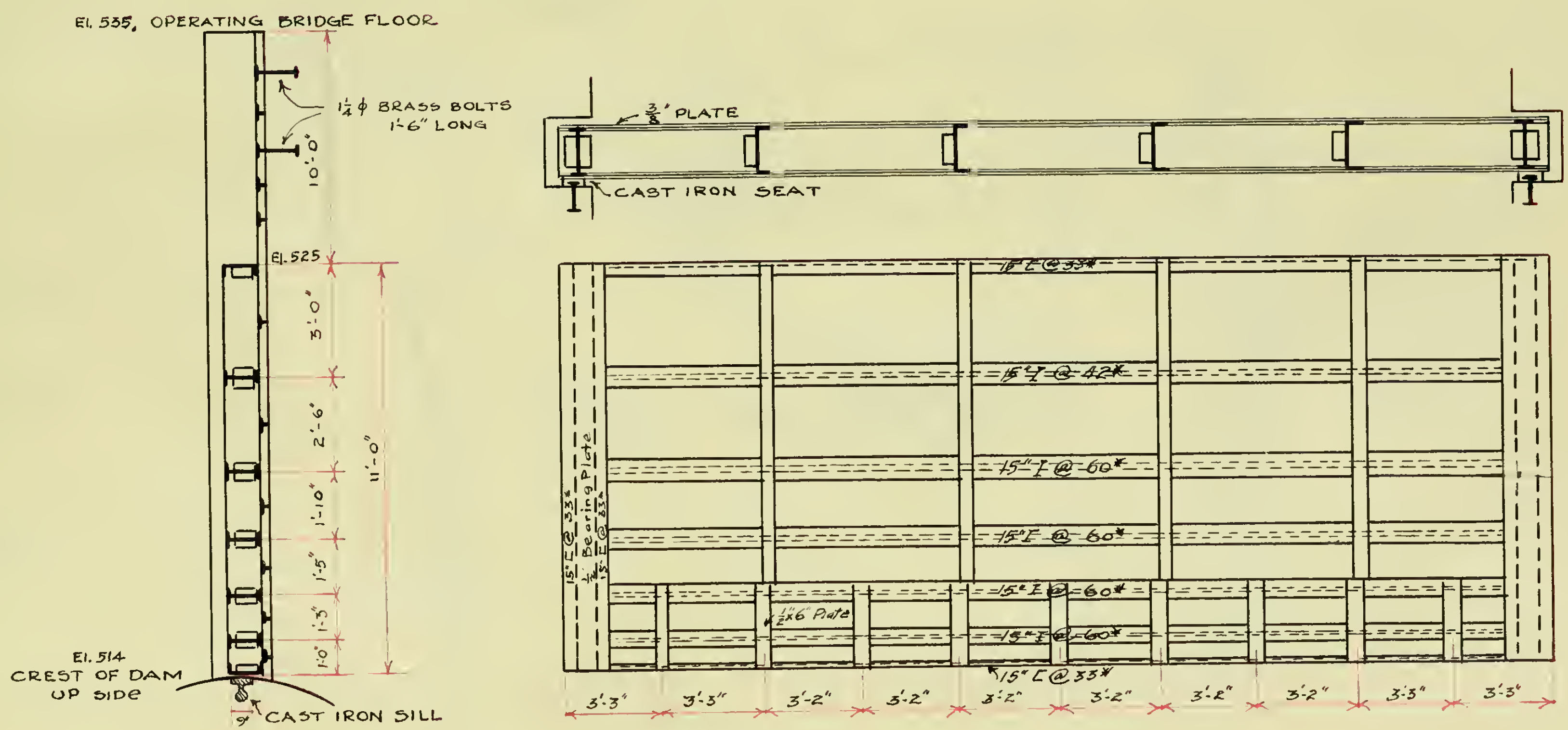


Fig. 2

Details of Power House Through the Main Unit at Center of Building

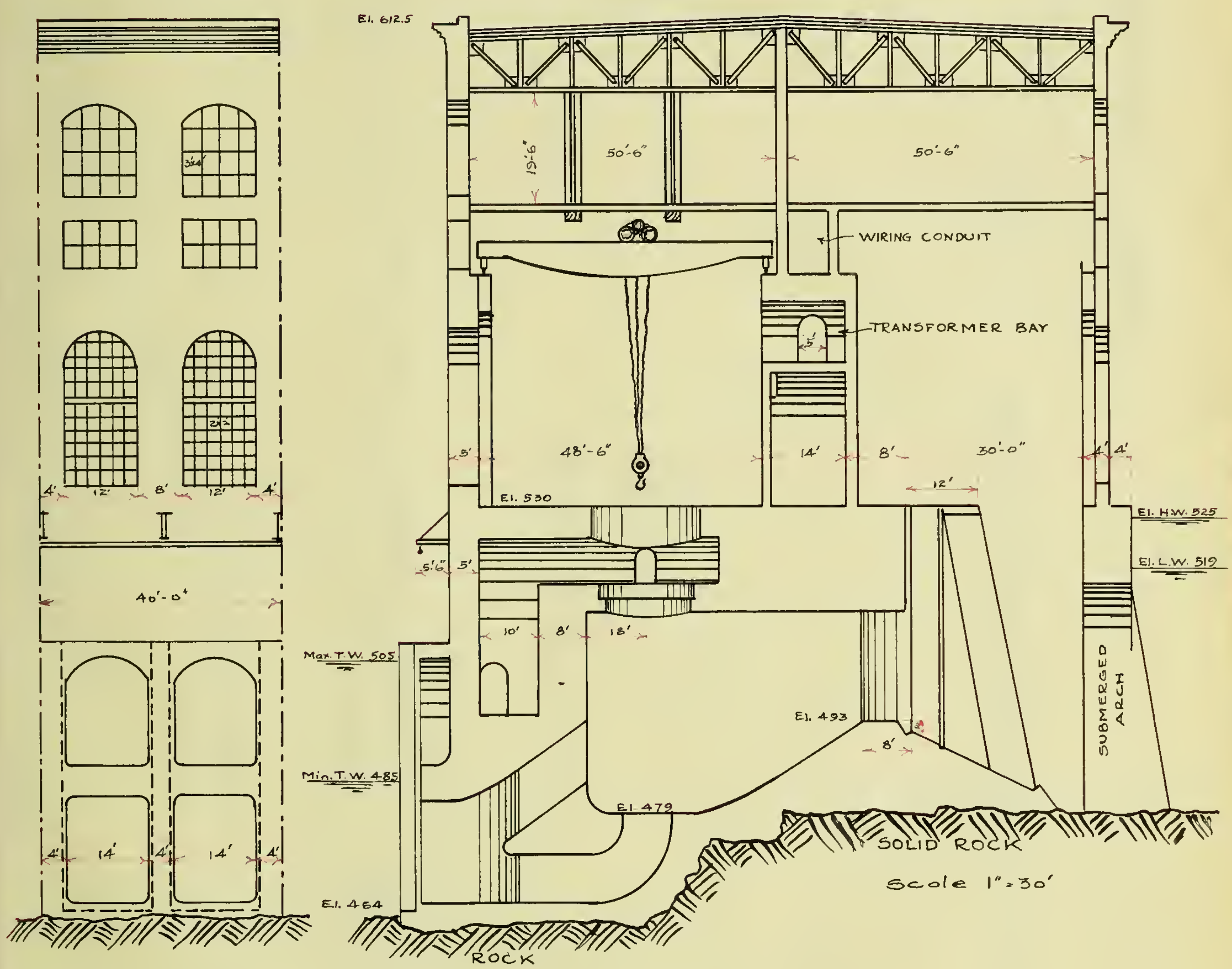


Fig. 3

Ice Chute

Ice-Fender

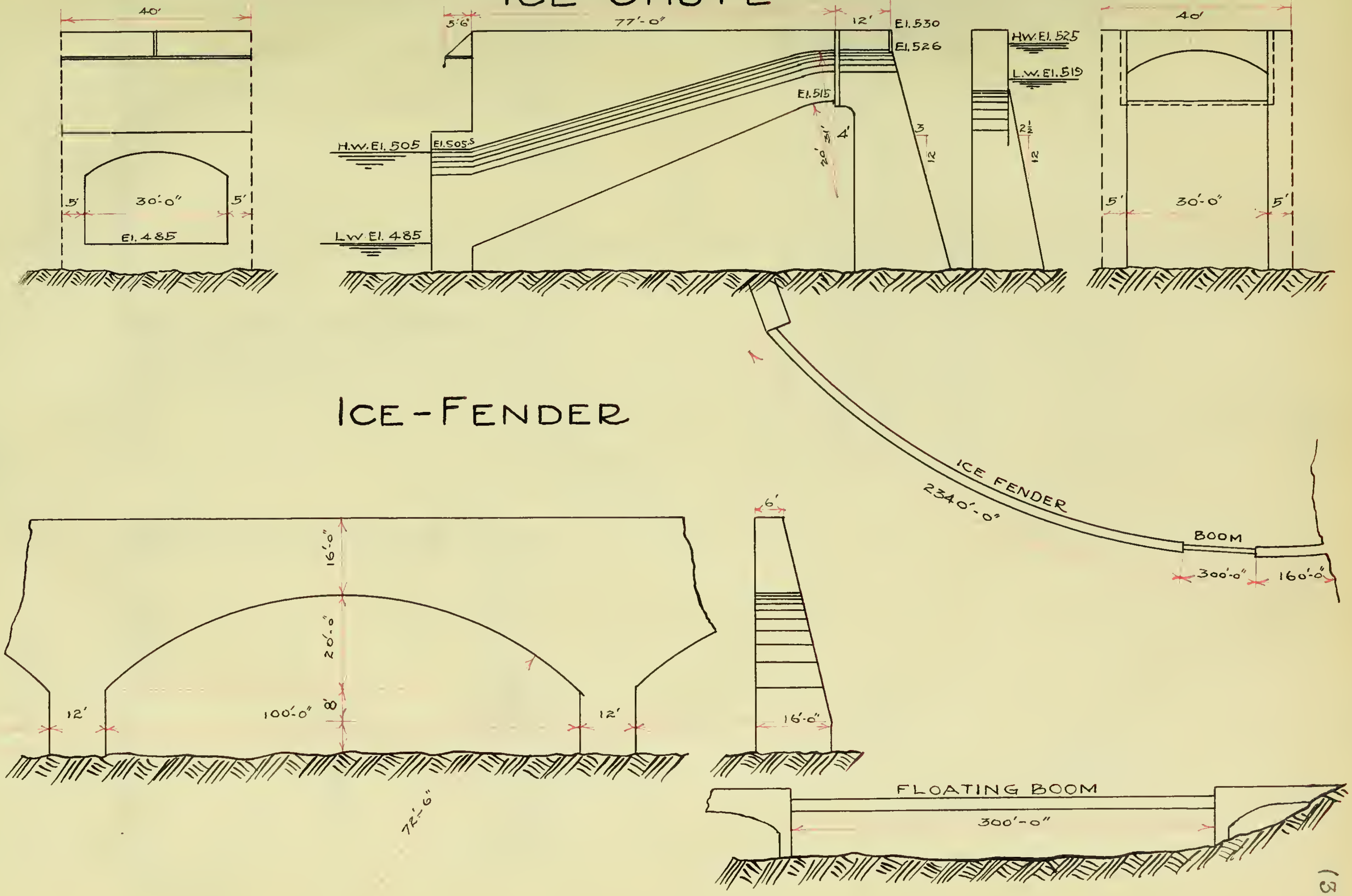
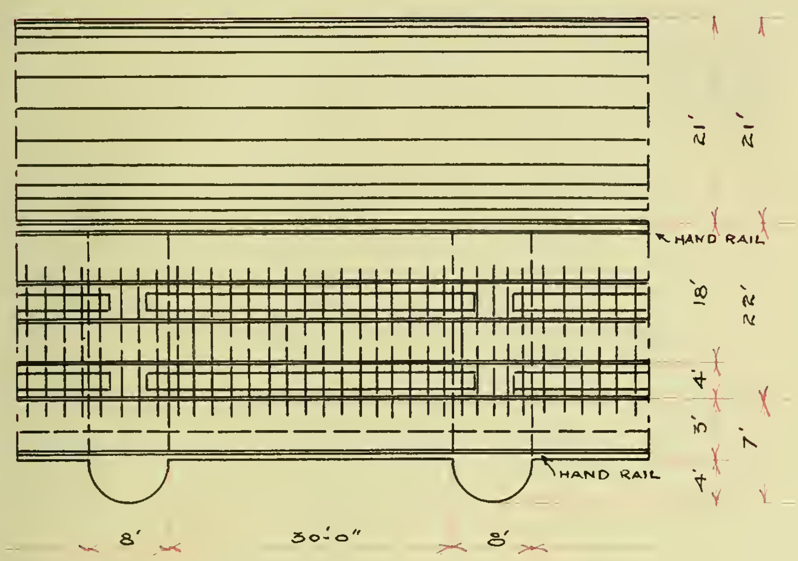
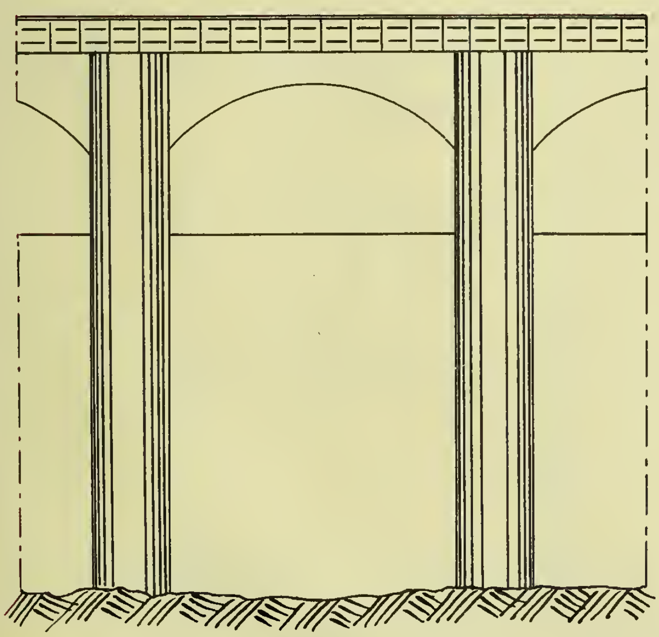


Fig. 4

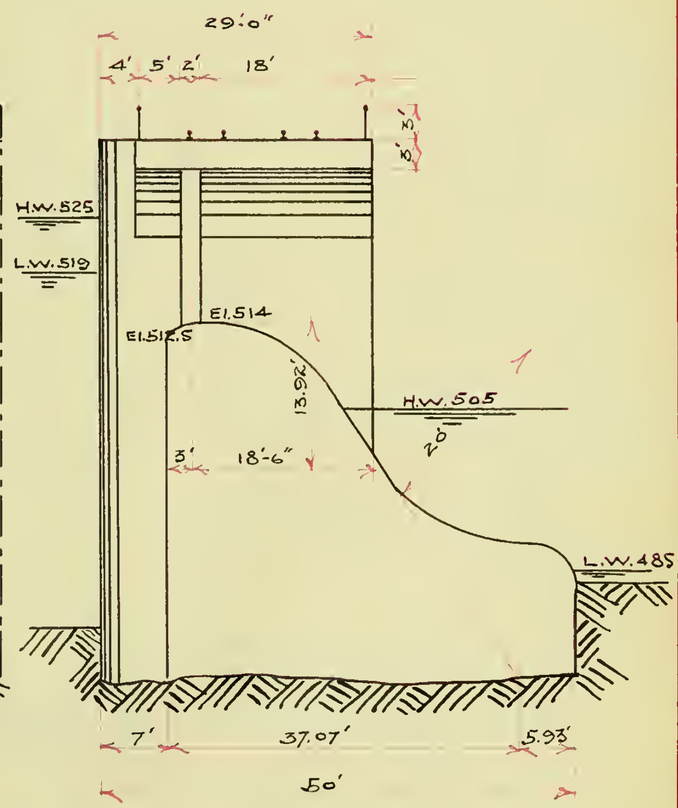
Dam Spillway



Plan



Elevation



Section

Fig. 5

PLAN OF LOCK & DRY DOCK

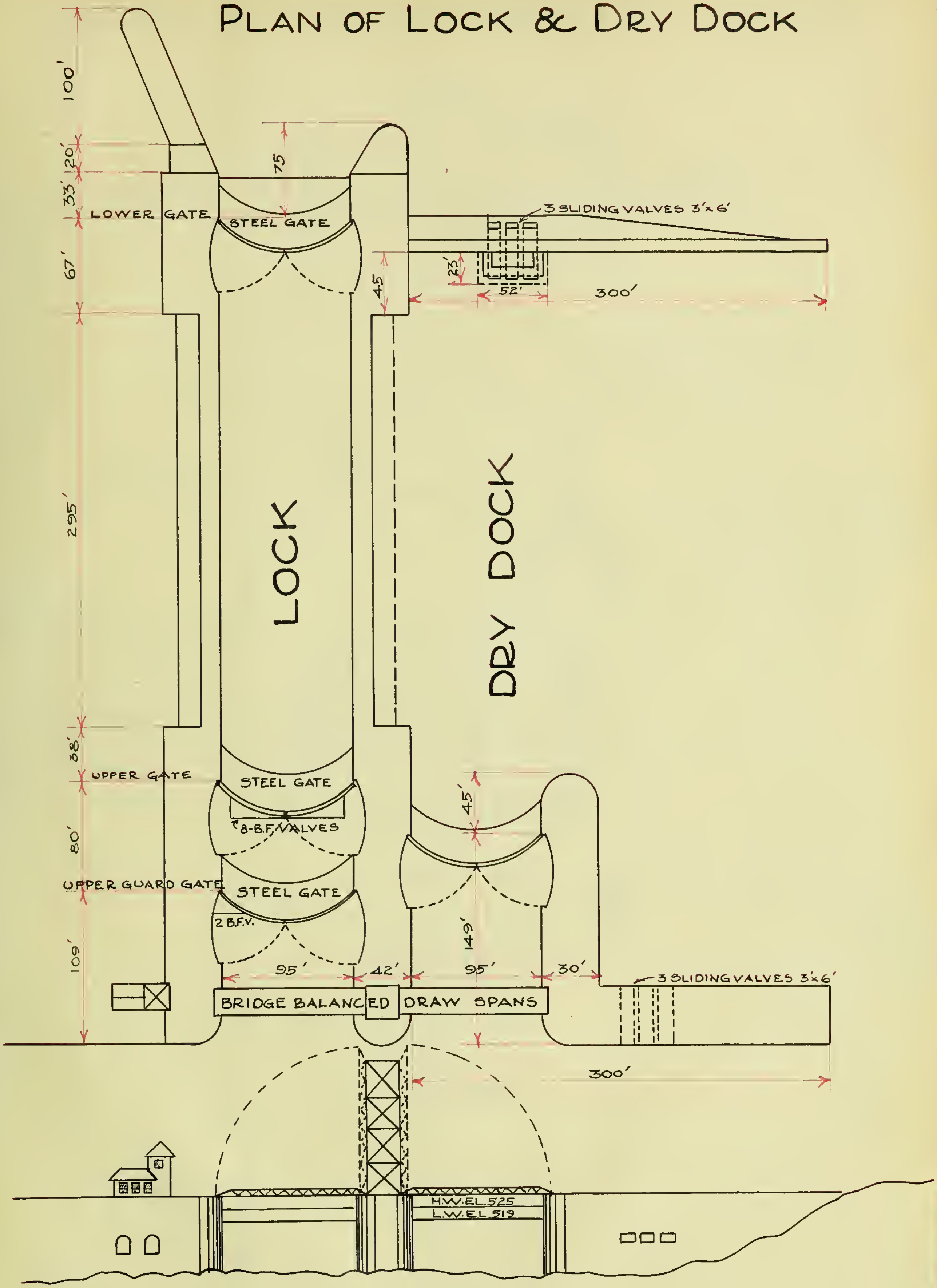


Fig. 6

Outside Elevation 10000 H.P. Turbine

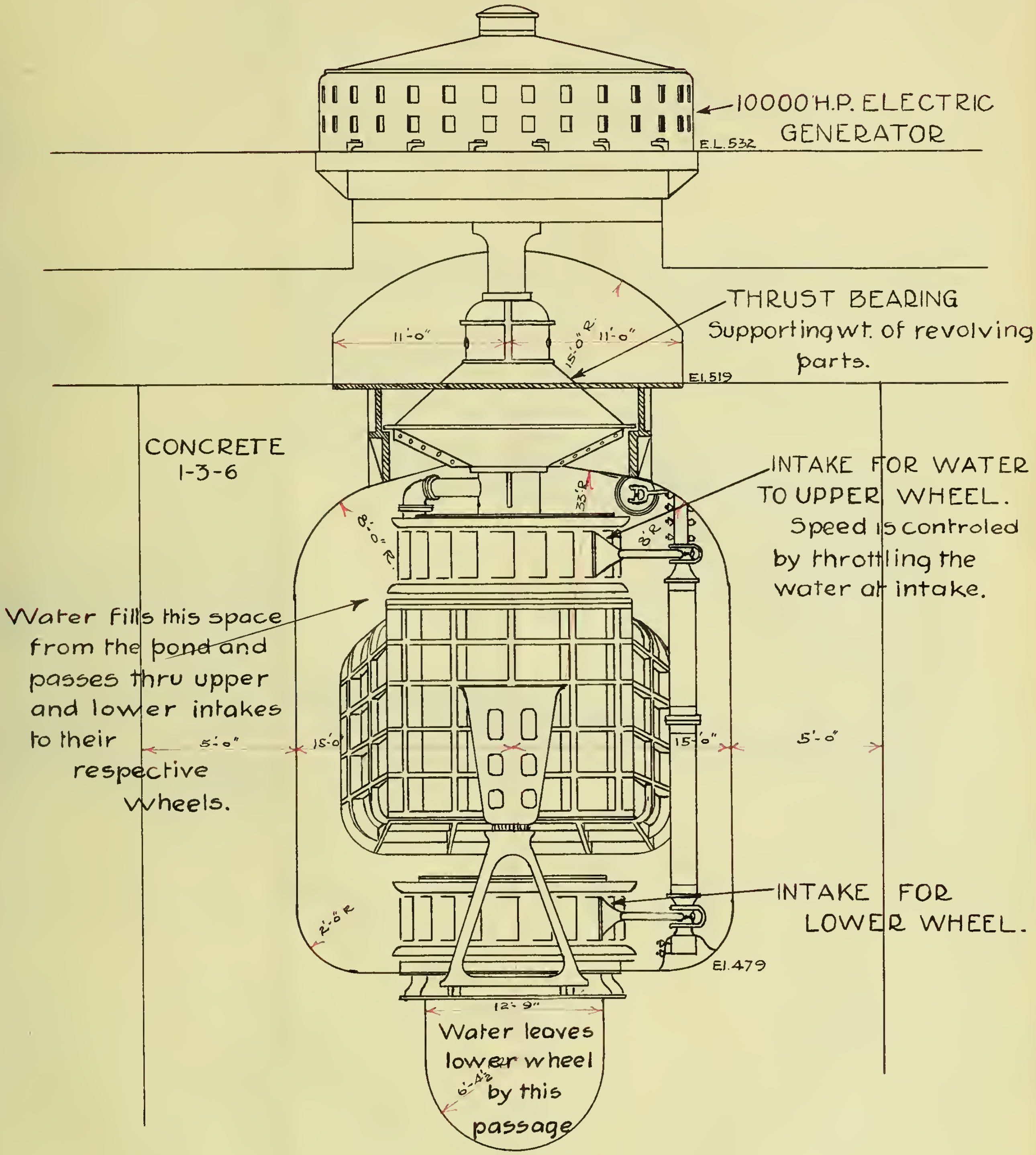
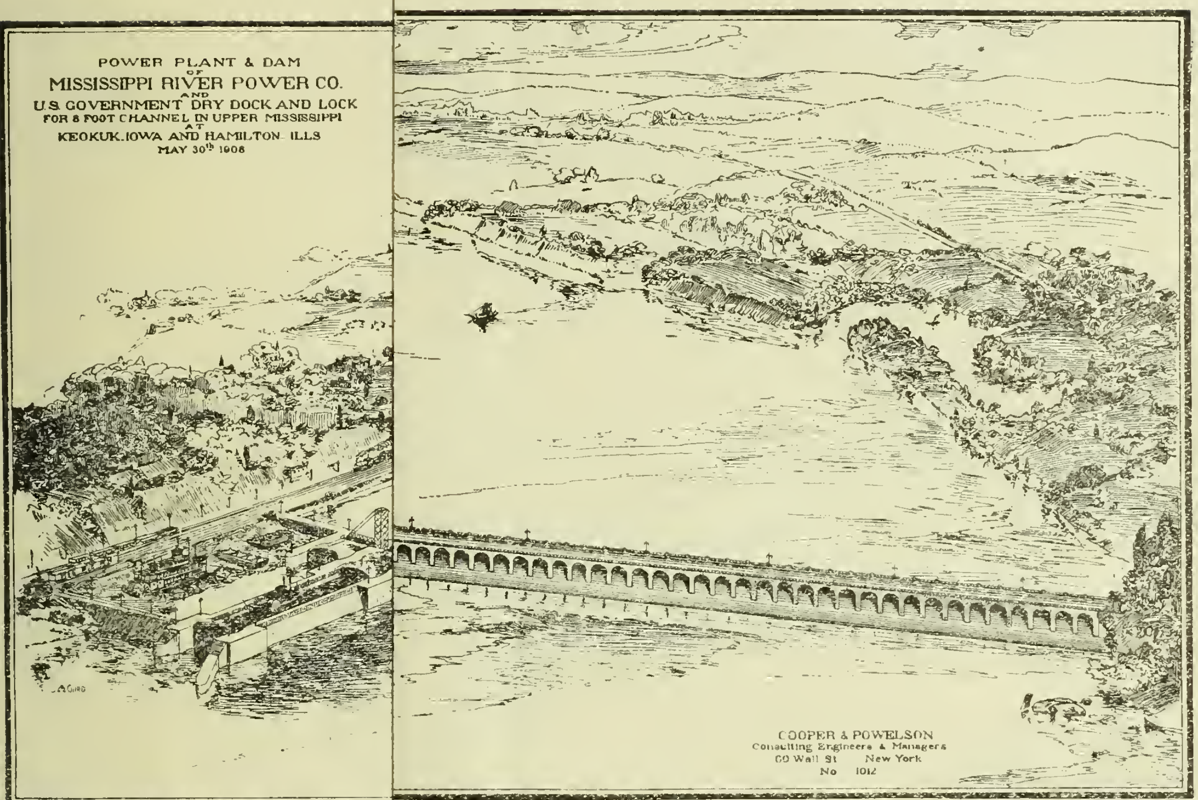
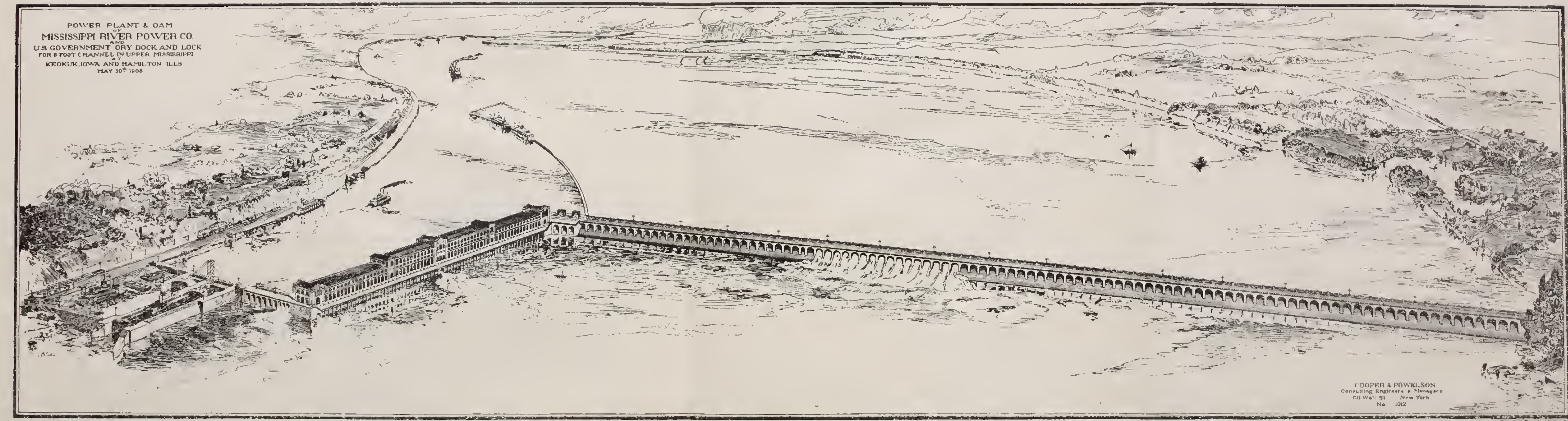


Fig. 7


POWER PLANT & DAM
OF
MISSISSIPPI RIVER POWER CO.
AND
U.S. GOVERNMENT DRY DOCK AND LOCK
FOR 8 FOOT CHANNEL IN UPPER MISSISSIPPI
AT
KEOKUK, IOWA AND HAMILTON, ILLS
MAY 30th 1908
COOPER & POWELSON
Consulting Engineers & Managers
60 Wall St New York
No 1012


POWER PLANT & DAM
OF
MISSISSIPPI RIVER POWER CO.
AND
U.S. GOVERNMENT DRY DOCK AND LOCK
FOR 6 FOOT CHANNEL IN UPPER MISSISSIPPI
AT
KEOKUK, IOWA AND HAMILTON ILLS
MAY 30th 1908
COOPER & POWELSON
Consulting Engineers & Managers
60 Wall St New York
No 1012